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DUST DEVILS AND AVIATION

by

F. BELL

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Extracted from - Meteorological Note No. 27, May 1969
Commonwealth Bureau of Meteorology

1. Introduction

This article was initiated during an Air Safety Symposium for General Aviation held at Longreach, Queensland, in October 1968, following a discussion on dust devils. Over one hundred pilots were present.

2. Frequency of Dust Devils

The occurrence of numerous dust devils over inland Queensland is so frequent that local residents regard them as a part of the Summer scenery and learn to live with discomforts that they cause. Pilots encounter dust devils so often that they do not report them, even when their experiences could be classified as 'frightening'. It would also seem that some voluntary observers have the same attitude, for while the local people talk of seeing at least ten dust devils in an hour or even at one time, this is not borne out by an inspection of the western Queensland stations' weather reports over the ten year period from 1958 to 1967 (See Table 1).

In this regard, it is considered that the phrasing of the code description of present weather and past weather is partly to blame, since there is no provision for reporting dust devils as such, except when they occur "within the last hour but not at the time of observation", also most of the voluntary stations report only at 9 a.m. and 3 p.m.

Replies to a questionnaire sent to general aviation pilots in western Queensland give the following information in regard to the numbers seen from aircraft in flight on various western routes -

Table 1

Dust Devils Reported in Synoptic Observations

Station	Years of Reports	Number of Occurrences
Mornington Island	1965-1967	1
Burketown	1958-1963	-
Donors' Hill	1958-1963	1
Croydon	1962-1963	-
Normanton	1958-1964	2
Georgetown	1958-1963	-
Richmond	1958-1964	3
Blackall	1958-1964	1
Tambo	1958-1963	1
Barcaldine	1962-1964	-
Isisford	1958-1963	2
Camooweal	1958-1964	-
Urandangie	1958-1964	21
Thargomindah	1958-1964	2
Quilpie	1958-1964	-
Adavale	1962-1963	2
Cunnamulla	1958-1964	-
Charleville	1958-1967	52
Bollon	1958-1963	-
Surat	1962-1963	-
St. George	1962-1964	-
Roma	1958-1964	-
Goondiwindi	1958-1964	-
Windorah	1958-1964	-
Boulia	1958-1964	4
Birdsville	1958-1964	2
Winton	1958-1964	-
Mt. Isa	1958-1964	1
Mt. Isa Mines	1965-1967	2
Mt. Isa Aerodrome	1966-1967	10
Longreach	1958-1964	1
Longreach Aerodrome	1966-1967	-
Cloncurry	1958-1967	158

Diamantina/Dajarra	Twenty in sight at most times, visible to 5,000 feet.
Tambo/Blackall	Six or seven at one time, with burnt timber ash to 8,000 feet.
Barcaldine	Ten at one time with grass at 4,000 feet.
Boulia/Bedourie	Forty in ten square miles, mostly to 1,000 feet, but six or seven visual to 6,000 feet.
West of 145°E	Counted thirty in the arc of the aircraft windscreen, visible to 5,000 feet.
Cunnamulla	Forty in an area at one time, some to 8,000 feet, but generally 5,000 to 6,000 feet.
Bourke to Longreach	Many over whole route, estimate hundreds were visible and large tufts of roly-poly grass at 5,000 feet.
Hughenden/Richmond	Five at one time with dust to 5,000 feet.
West of Bourke	Sometimes one hundred can be seen at one time from an aircraft.

It must be acknowledged that large dust devils occur in western Queensland in large numbers during favourable weather situations, and these are often effective to a considerable altitude above ground level.

3. Severity at Cruise Level

General aviation pilots were asked to recount some of their more hazardous experiences in dust devil conditions, and the following selections give a good indication of their effect on light aircraft. Although most of the pilots are adamant that dust devils are not a really dangerous phenomenon, their experiences clearly show that the pilots need to develop special techniques for flying in dust devil conditions in order to accomplish their various flights without mishap in flight or in take-offs and landings.

In the Cunnamulla area in January 1965, Mr. E. Morse flew a C172 at flight level (above 11,000 feet) in cloudless skies when surface winds were light and variable and surface temperatures above 100°F; there were no dust devils visible at flight level but many could be seen below. The Cessna was heavily loaded and the pilot had his wife and three children as passengers. The pilot presumes that he was in the invisible top of a cauliflowering dust devil.

"In spite of full corrective control and full power, the aircraft rolled inverted and was flown out underneath. I could not climb higher and was forced to descend to maintain any control."

Another pilot, E.J. Connellan of Alice Springs, flying a Percival Gull 6 at The Granites, flew across the strip at 400 feet to inspect the surface when a whirlwind struck the aircraft.

"My impressions as a pilot were that the aircraft was on its tail - though, no doubt, this impression greatly exaggerated the actual facts. However, it was a fact that the air speed went from about 110 m.p.h. to less than 40 m.p.h. and the aircraft stalled in a nose high position. This incident was really due to my inattention, or to my distraction in favour of inspecting the surface of the strip which was wet. Had I been looking where I was going, I would have had the nose down and speed up and negotiated the whirlwind successfully. As it was, my engine stopped because the float in the carburettor had been jammed in the fully

down position, and I was required to carry out a forced landing from a somewhat precarious position regarding height and airspeed."

A D.C.A. engineer advises that the Gypsy 6 carburettor has since been modified to prevent this type of occurrence.

4. Growth Rate

Since the Longreach symposium, Mr. Wilson has taken special notice of dust devils. On a flight to the Bedourie area, he timed the growth of a whirly whirl forty miles west of Jundah, while flying a C172 at 6,500 feet.

"When first seen abeam of the aircraft, the column was estimated at 1,500 to 2,000 feet high, within two minutes the column was well above the cruising height of the aircraft and estimated to be 7,500 feet.

The weather conditions at this time are given by Mr. Wilson as surface wind light and variable, surface temperature 100°F, flight level wind variable at 5 kts and flight temperature 50°F, cloudless skies with four dust devils visible at any time and sometimes eight at once.

The updraft near a dust devil was roughly estimated at Charleville from a radar wind flight. A 100 gram balloon with a 12 inch target and 700 gm free lift rises at approximately 310m per minute. During a dust devil period at 3 p.m., the following ascent rates were found (Table 2).

Table 2

Ascent Rates of 100 gm balloon
during a dust devil period at 3 p.m.

Minutes	Height	Difference per Minute	
		metres	feet
1	600	-	-
2	1200	600	1968
3	1820	620	2034
4	2700	880	2887
5	3620	920	3018
6	3990	370	1214
7	4300	310	1017
8	4610	310	1017

This gives an additional height of 2,000 feet in the fifth minute and lends credence to Mr. Wilson's observation.

Other remarks noticed in the replies refer to the winds of a Meta Sokol (reportedly very strong) 'oil canning' in the turbulence near dust devils. Air-

craft being lifted from 1,000 to 2,000 feet were common and some were lifted 4,000 feet. Aircraft violently yawing 20 degrees or more, and/or rolling were also common occurrences.

5. Severity at Landing or Take-off

Mr. E.J. Connellan was a few feet above ground after take-off when he had to fly through a dust devil. The severity of the turbulence stopped the engine and the carburettor float of the Percival Gull was found to be jammed in the fully down position.

At Nanda, an aircraft made a landing, with a surface wind of 20 to 30 kts and gusty, when small numbers of scattered dust devils were visible and the surface temperature was 100°F.

"At the last moment, a dust devil several hundred feet high crossed the track of the aircraft which slewed and twisted and alternately rolled on each wheel slightly. It took every effort to avoid disaster. This whirly whirl was one of a group of three, and was not visible until it moved on to an ungrassed area, where it picked up dust. For a short while the aircraft was lifted clear of the ground and at just on or below stalling speed, this was unpleasant."

At Hartree, a P.A. 32 was half through its landing roll when an invisible whirly whirl lifted the aircraft about twenty feet, tossed it about a little and then dropped it on the runway right way up. The pilot turned off the ignition and hoped for the best, but if he had had more flying speed, he would have applied full power to gain more control.

At Richmond, Queensland, a C150 took off in a 3 kt/130° wind, the temperature being 103°F and the sky cloudless; at about 100 feet the plane met a whirly whirl. The pilot states that this was probably forming and was not visible at take-off, but later became a very large dust devil. The first indication was a sudden shooting upwards of the aircraft for about 200 feet, and then a sudden stop that nearly tore the safety belt out and bumped the pilot's head on the roof. The airspeed needle shot right up into the red mark. The aircraft kept an even keel but rocked a little. The pilot considers that the only real danger was the airspeed which showed an increase of 60 kt; if the whirly whirl had been fully developed the overloading on the wings might have caused an accident.

6. Severity at Ground Level

Mr. Hardy of Richmond has seen two house roofs lifted by whirly whirls and the galvanised iron carried for half a mile. He estimates that any aircraft under 2,000 lb would certainly be lifted if not pegged down.

At Eindorah, a P.A. 32 was tied down with 5/8 inch diameter rope. The whirly whirl broke two of the ropes, but as two ropes were still holding, the aircraft was tipped on its back and bounced up and down.

At Dubbo, a Piper Colt was wheeled from the hangar for a 100 hourly inspection, and before the work gang had time to go back inside, a whirly whirl turned it upside down and wrecked it.

Other comments on the damage by the dust devils included removal of 2,000 gallon tanks and oil drums, demolishing of small sheds, weak rooted trees blown over and washing disappearing from clothes lines.

7. Basic Conditions of Formation

The conditions for the occurrence of dust devils are fairly well known. Geographically, dust devils are most frequently seen in broad arid basins with little surface vegetation and much loose surface dust, although the dust need not be thick. Dust devils frequently occur in country where sparse vegetation and scattered trees are intermittent with areas of no trees or grass, and in this type of country the dust devils are intermittently visible. Dust devils are seldom seen over salt marshes, well watered grasslands or thick forests.

Meteorologically, dust devil formation requires strong surface heating for some hours and little surface wind. This implies a decidedly super adiabatic lapse rate near the surface with surface soil temperatures in the region of 140°F to 160°F, cloudless skies or well scattered high level cumulus. These conditions prevail frequently in Australia during the warmer months.

Dust devils also occur in a rough line formation along the sea breeze front in hot arid or semi-arid regions and have been reported in the Gulf country of Queensland and the northwest of Western Australia. The invisible type of "dust devils" called whirly whirls, occur after a good rain season when there is more grass.

The details of dust devils, their shape, size, movements, life duration, temperature, pressure and wind changes do not concern the forecaster or the aircraft operator so much as their time and locality of occurrence, and the height to which they may be effective. Much has been written on dust devil details in various journals for many years and, besides making interesting reading, these articles highlight the many aspects of dust devil structures, which are as yet unexplained, and the complexity of air movement in even small scale disturbances.

8. Conclusions

The above extracts clearly show that dust devils, whether visible or not, are a hazard to light aircraft in the take-off and landing phases. Near the ground, the disturbances have their greatest energy and when the pilot's attention is usually concentrated on his manouevre.

At flight levels, the pilot has more air space and consequently the dangers are not so great, but loss of control of the aircraft at any time is very disturbing. This danger appears to occur in the upper part of the disturbances where the rising air column changes its structure by spreading and containing areas of subsiding air which find their own density level after having been carried higher than that level by the dust devil's inertia. In this region, the aircraft has no lift and all controls are sloppy and unresponsive. From the data received, this region is seldom visible and extends for about 2,000 feet above the visible dust-filled column of the dust devil. It is not always directly above the dust column, but will usually follow the extension of the line of dust, i.e. if the dust column is vertical, then the area is usually directly above it, if the dust column is sinuous, then the rough area is beyond and in line with the path of the dust column.

On the surface, all light aircraft must be securely pegged down if not parked in substantial hangars.

The extracts also show the necessity for area weather forecasts covering inland regions of Australia, to make special reference to the probability of dust devil conditions existing in the various regions. This is needed to alert the inland residents and aviators of the need for precautions against damage, and for caution in the planning and operation of their various aircraft flights.

There are still two further points in connection with dust devils and their effect on the safe and economic operation of aircraft.

The first concerns training. Pilots trained at coastal aviation schools will not meet with the large dust devil and its attendant problems during their training period. Dust devil flying requires special techniques and this is also evidenced in the replies from the pilots, which include remarks such as -

" In dust devil areas, watch the tall grass movement when landing as this will give indication of the invisible dust devil."

" It is better to fly low and take harder turbulence, than to wallow uncontrollably at the mushrooming level."

" Confine flying to morning hours whenever possible."

" Avoid dust devils wherever possible, and delay landing until the landing end of the strip is clear of dust devils."

" Dust devils are not dangerous to experienced pilots but must be treated with respect at take-off and landing."

If the training deficiency in this regard is not rectified by a period of dual flying in western Queensland, then a new pilot's first experience with a dust devil on landing could result in a serious accident.

The second aviation aspect concerns the shortening of the life of various aircraft components. The life of various metal parts of an aircraft is limited by the size and number of various stresses and strains to which it is subjected. Once this limit is reached, then the part begins to suffer from metal fatigue and must be replaced. Stresses due to normal aircraft manoeuvres under various loads can be reasonably estimated, and structures are built to specifications which provide a reasonable life in flying hours. In these estimates, there is due allowance made for the effects of average turbulence. Inland Australia has higher than average turbulence conditions, and consequently deterioration of aircraft parts occurs sooner than in other parts of Australia or overseas. Large areas of dust devils on frequent occasions play a large part in stepping up the cost of light aircraft maintenance.

Although the remarks quoted in this article are connected mainly with western Queensland, they could easily have been originated in the inland parts of other Australian states. Arthur H. Afflock in "The Wandering Years" talks of the flying conditions in the Ord River area during the DH 84 years of MacRobertson Miller Airline. There he describes how the aircraft with three men hanging on and streaming behind, was slammed into the stockyards by a willy willy. He also mentions Turner River, Western Australia, as a breeding ground of dust devils where he counted as many as forty columns of dust from the ground to several thousands of feet.

ILLUSTRATED LECTURE

by

Mr. LEN BEADELL M.B.E.

We were extremely fortunate to have Mr. Len, "Gun-barrel", Beadell, M.B.E., as the guest speaker at our Meeting on 2nd October. As the preface to his book "Too Long in the Bush" states, "straight as a gun barrel, they bulldozed their way through saltbush, sand dunes, desert and salt lakes to make Australia's most incredible highway". This highway extended from Kulgera, just south of Alice Springs, to Warburton Ranges Mission in Western Australia and passes through the "Giles" Weather Station which is about 400 miles WSW of Alice Springs.

Len's lecture was illustrated with an outstanding set of coloured slides depicting not only the hazardous nature of the country which they traversed, but also the fauna and flora together with many interesting shots of the Australian aborigines in their most primitive state.

One native had a home-made artificial foot to replace the one he lost in a spear fight. It was about twelve inches in diameter and consisted of a tightly wound bundle of rags and other materials bound with home-made twine. He is reputed to have walked seventy five miles in one day without a retread.

Len Beadell and his gang were a familiar sight around the Giles Weather Station for many years, and the walls on the inside of the mess are covered with sketches made by Len of some of the celebrities who have been stationed at Giles.

The humorous stories he told are too numerous to recount and the slides had to be seen to be believed, but for those who were unfortunate enough not to be in attendance the whole story of his wonderful achievements, for which he was awarded the M.B.E. in 1958, are told in his book "Too Long in the Bush".

CONTROL OF INFORMATION POLLUTION

by

ARNOLD COURT
Professor of Climatology,
San Fernando Valley State College, Northridge, California.

Pollution is the paramount problem of mankind, and its alleviation and eventual elimination require drastic shifts in procedure and, more importantly, in basic outlook. Pollution of the environment - air, water, land - was the first to be recognized, and modest progress has been made against these forms. Pollution of population has been recognized for the last few decades, and thus far only very halting steps have been taken toward its prevention. Pollution of information, perhaps the most insidious of all, has been decried almost as long, but its basic similarity to other pollutions has not been recognized; therefore no concerted or constructive preventive procedures have been proposed.

Pollution of the atmosphere is simply the insertion into it of more gases, particulates, or acoustic waves than it can dissipate before they cause undesirable or harmful effects; pollution of rivers, lakes, ocean, and land by detergents, pesticides heat or radioactive materials is similar. Population pollution is the creation of more people than the earth can house and nourish. And the growing pollution of information is the production and preservation of more material than can be heard or seen by those to whom it is addressed, and hence cannot be assimilated and used by them.

Pollution of any kind can be prevented only by reducing the production rate to a level not greater than the assimiliation rate. Some aid can be given through increasing the assimilation rate, whether by forced mixing of air, by introducing more efficient bacteria into the disposal plant, by developing some intensive agriculture, or by insisting on short but comprehensive titles, clear slides, and proper references, and providing complete indexes and elaborate information retrieval systems. But the major goal must be less production of materials that pollute environment, population, and information channels.

Such reduction in output can be achieved only after a massive reversal of human attitudes. To decrease atmospheric pollution, a smoking chimney was changed from a sign of prosperity, as it was regarded a century ago, to a mark of slovenliness. The right of a landowner to use water as he saw fit was replaced by the duty to pass it on undiminished in quality. When a large family is considered to be not a sign of affluence or virility but one of ignorance or intemperance, population will decrease.

Information pollution can be reduced only by drastic reversals of hallowed customs in all fields of science - academic, industrial, governmental, and organizational. No longer should a scientist be rewarded according to the quantity of his pronouncements and publications; instead, he should be punished for prolixity and reproved for repetition. Quality rather than quantity must be the criterion of accomplishment. Despite the difficulties in measuring quality, whether of automobile exhaust emissions, pesticide residues, or scientific writing, it must be evaluated by promotion and editorial committees no less than by environmental scientists.

Two other reversals of custom can be attained more readily in the fight against information pollution. Administrators should remove immediately the usual requirement that a paper be presented by those paid, or even permitted, to attend a meeting or convention. Programs of scientific meetings are cluttered with old papers, poor papers, pointless papers, thrown together solely to justify the trip. Some other basis must be found for the decision of who may go.

Journals should require, in the preface of every paper (or as a first page footnote), a complete statement of all other places in which a substantial part of the same material has been presented, orally or in writing; the qualification, usually applicable, of "without material change" will be helpful. Entirely too much time is wasted in reading an article that seems vaguely familiar, and in straining the memory until the reader finally recalls that he heard or read this material two years ago - and it wasn't much good then either. Repetition of the same material in widely differing media may have merit, but verbatim reprinting is less confusing than artful rewriting.

Removal of the requirements for presenting a paper in order to attend a convention, or writing one to qualify for promotion, and insistence on complete disclosure of all previous versions of the fewer papers written in such a more relaxed atmosphere, will help alleviate the information pollution.

TELEPHONE
I'M GETTING MARRIED TOMORROW— COULD YOU TELL ME WHAT IT WILL BE LIKE?
SORRY, BUT WE ONLY FORECAST THE WEATHER.
KARLA

Address by

Commander W. HODGE

U.S.N. Flight Commander 11 Squadron, R.A.A.F. Edinburgh, S.A.

Meeting Tuesday 4th August, 1970

It has been a long time since I have seen a movie like "Hurricane" and it has been an awful long time since I have been that scared.

I'd like to thank you very much, Mr. Hogan and your wonderful Association for asking me to drop in tonight. It has been all of 13 years since I have flown into one of those storms, but it seems just like yesterday.

The reconnaissance effort that you saw this evening in the film "Hurricane" is actually five or ten years ahead of anything that I have actually undergone. When I left the particular field of hurricane reconnaissance it was still in the embryonic state. That is to say, all they knew ashore was what we, in the aircraft, could send them back. If we knew that the storm centre was at such and such a latitude, such and such a longitude, we would send this information to the Meteorologists, one of whom was on your screen this evening, Mr. Brady Norton, who is the Chief Meteorologist in Miami, Florida. It was up to him, lock, stock and barrel, to say to the U.S. Government and the Department of Interior - "Ladies and Gentlemen, this is where the storm is, this is where it is going to go, this is what is going to happen". He based all of his information on what we brought back from our hurricane reconnaissance aircraft and so it behoved us in our particular field of endeavour to make sure for Mr. Brady Norton and his people back at Weather Central that we gave them the proper temperature, the proper pressure and the proper location, latitude, longitude etc. Now, if we failed to do this, any extrapolations, and, after all, weather forecasting is nothing more than a little therapeutic extrapolation at the very best, of the ultimate destination and intensity of the storm would be difficult to determine.

Well, I have worked for these people for quite some time and I am familiar with a lot of their secrets.They are very shrewd and they hide behind such phrases as adiabatic, subsidence, clockwise circulation, counter-clockwise or, as I should say here in Australia, anti-clockwise. All in all, they are hiding behind all of these mystical terms, but believe me, Ladies and Gentlemen, the terminolgy that they use, the nomograms that they use, the very basis upon which all of the extrapolations are founded are only as good as the information that they have at their disposal and, from this particular movie tonight, back track another ten years in time and the only thing they had at their finger tips was what we gave them. Now, that could be good, as good as we tried to make it, or it could be bad, as bad as we didn't try to make it.

Now, driving a car in this day and age from A to B is pretty difficult. Driving an aeroplane in this day and age is a lot easier. But driving an aircraft without all of the niceties of life, without all of the wonderful electronic aids to navigation that we have today, we found a little tedious, a little hard to do, a little tough to negotiate. When we had to take off, for example, and if I may bore you with a flight profile for a few moments, from point A, which was our home point, Jacksonville, Florida, which, if you are familiar with the east coast of the United States, is up on the Northeastern coast of the State of Florida, we would fan out from there to restage from Sanjuan, Puerto Rico, which is on the northeast corner of the Greater Antilles. Then we would restage from there all the way over to Ascension Island or towards Lagos in the Azores, looking for a sign, looking for something for the Meteorologists to make some sense out of. Looking for a tropical depression, a tropical wave, something that went from A to B but which just didn't add up. Looking for something that these gentlemen can tear into with their background and their training and say "If this wave continues, and if this happens, and if so and so occurs, we are going from a wave to a deepening depression to perhaps a tropical cyclone to perhaps a hurricane".

I noticed a gentleman in the film tonight said 75 knots or above was a hurricane. This, indeed, is a recognised wind velocity recognised by the International Weather people that denotes a cyclone, as you call it in the southern hemisphere, or a hurricane as we call it in the northern hemisphere, as distinct from just a cyclonic storm, or a tropical storm. The gentlemen in the Meteorological Office then look at this very closely. They get out their scalpels and they start to dissect it. They need more information, like a Doctor needs to know a pulse, needs to know heart beats, he needs to know all the things that tell him how sick the patient is, how the patient is going to fare one way or another. The Meteorologists need to produce an exact prognosis of this particular storm. This is where we came into the picture. Once we in the Hurricane Hunter Squadron located a tropical depression we stayed on that storm 24 hours a day, 7 days a week, until it had lost its intensity as a storm, or, in other words, it had run its gauntlet over the land mass, or it was no longer, in accordance with the United States Weather Bureau, considered a threat to the coast of the United States.

After forecasting the movement of the storm, the Weather Bureau, based on the information that they had received from the U.S. Navy Reconnaissance Aircraft, then set about to find out whether this predicted movement would result in its affecting the land. You probably noticed in the film this evening that they glossed over very rapidly the idea that the storm was encroaching on land; it was coming and the hurricane warnings were given out. This is not a very lightly-taken responsibility by the Weather Department or the Navy. When a situation like this occurs they study and re-study every piece of information so that they make sure that everyone is notified that should be notified, but, on the other hand, no one is put to a false alarm nor caused any undue panic, which I'm sure you could realise would be much more serious in many instances in metropolitan areas than the storm itself. Once this is ascertained and the storm has gone from a depression to a closed circulation to hurricane-force winds the aircraft then really lower their big guns on it. We used to fly in the Super Constellation; you may recall there was only one clip of the aircraft in the film, that was a very funny old four-engine aircraft with big knobs and bumps all over it, taking off and climbing up into the sky, going into the storm at high altitude, penetrating the eye of the storm and dropping what is called a radiosonde. The radiosonde used to relay back to the aircraft pressure, dry bulb and wet bulb temperatures, wind direction and velocity and so on. This, in turn, was interpreted by a graduate Meteorologist aboard the aircraft who in turn put it into a cryptic coded message and sent it back to the mainland. As the storm progressed towards the mainland from out to sea we were able to actually relay radar photographs of the storm that we picked up on our radar back to the mainland itself, so that the Meteorologists could analyse and further correlate all the information we were sending back and update the advices and warnings they were giving to the local populous.

Well that's it in a nutshell. I have seen, unfortunately, at one particular time, 3 hurricanes going at once, 2 in the Gulf of Mexico and one off the eastern seaboard of the United States. You had to duck quick to miss one on take off. So we really had our hands full. Particularly in the old famous breeding ground in the Gulf of Mexico. When one gets in there and disappears off the face of the earth for a week or so, heaven knows, anything can happen.

Now the statement I have just made is, fortunately, no longer true. In this day and age of satellite reconnaissance and so forth you can have these things pretty well pinpointed. However, there is no substitution for the ability of an aircraft with a crew that is qualified and trained to go in at low level to ensure that all the temperature, pressure, humidity, wind flow, velocity, direction are sent back and this is why as long as we'll have hurricane forecasting we'll possibly have aircraft going into them.

As far as the actual energy these things develop, it is actually quite inconceivable - at first I couldn't believe it. A full grown mature hurricane still in a tropical or sub-tropical condition has the same amount of energy that would be equivalent to 50 H-type atomic bombs. Now that's 50 times 20,000 tons of TNT. You can imagine the tremendous forces that are at work in this holocaust. Predicting the flow of one of these is like predicting what the wife is going to do with next week's pay cheque. As a matter of fact, Brady Norton, the gentleman in the film tonight, who is a fellow of some repute in the United States, when queried why they named hurricanes after women said "because they are just as unpredictable as women". That's it in a nutshell, they really and truly are unpredictable.

I'd like to say, and I'm not a weather expert, I don't think you will ever have the fear in this area of what we saw on the screen this evening. We certainly will have some adverse weather but I don't think we will ever get the closed-circulation that you would get in the tropical or sub-tropical zones. You'll certainly get some bad weather but with a group of people like John Hogan and his team of experts, there is no reason in the world why you shouldn't be able to combat any of it.

CROSBY WEATHER

KENNETH G. RICHARDS

Mellonics Div., Litton Systems Inc., Monterey, Calif.

From "WEATHERWISE" Vol. 22, No. 6, December 1969

Out in Monterey, California, they have a local phenomena called "Crosby Weather". It occurs every January during the Bing Crosby Pro-Am Golf tournament. You will not find it in the Glossary of Meteorology, but golfers and golfing fans will tell you it is a very real thing. It is sometimes referred to as "the world's greatest argument for indoor golf".

Local meteorologists, who perhaps regard unusual weather with a less jaundiced eye, decided to investigate the outcries of the popular press. Bill Woodworth, who is head of the Environmental Sciences Department, Mellonics/Litton, rallied a corps of volunteers to make a definite study. Newspaper files dating back to 1949 were researched and compared with observations recorded by the Naval Weather Service detachment at the nearby airport. Historical weather map series were consulted. Local oldtimers were interviewed and gave firsthand accounts of the "year of the big blow" in 1952 and of the "blizzard" that dumped a quarter-inch of snow back in '62.

It became evident, however, that a discrepancy existed between the weather conditions described at the golf courses and those observed at the airport. Local weathermen have always recognised this fact of topographic influence. The airport lies in the lee of a range of hills to the west and south, while the three Crosby courses (Pebble Beach, Spyglass Hill and Cypress Point) are fully exposed to the ocean. Accurate observations from the Pebble Beach area were not available for comparison, however.

In 1968, equipped with a hand anemometer and sling psychrometer, Bill Woodworth became the official weather observer for the Crosby "Clambake". Temperature differences between the golf courses and the airport were not found to be extreme, but there was a significant difference in measured wind velocities. On one particular afternoon, south to southwest gusts in excess of 30 knots were observed at Cypress Point, while the highest wind recorded at the airport was 6 knots. Crosby Weather is discussed by the galleries as much as the golf game itself, and Bing and the tournament officials were interested in Bill's findings.

At the request of the executive committee, Woodworth assembled his volunteers for a major effort in 1969. To kick-off the program, three attractively uniformed "Weather Maids" were on the courses during the practice rounds to hand out a pamphlet of "Crosby Weather Facts". A press release was also prepared for the working press.

On each tournament day, observers stationed on each course with hand anemometers and electric psychrometers relayed observations to a central command post. Scheduled observations were called to the ESSA-WB forecast centre at Redwood City (near San Francisco). A "Crosby Weather Board" was displayed at the press room and manned by volunteer meteorologists. Official observations from the three courses, and a special forecast prepared by Gustafson at Redwood City were posted for the ready reference of the press corps.

As expected, weather became the main topic of discussion throughout the 1969 tournament. As for the record-breaking rains, (and flooding in some parts of California) it was just "Crosby Weather" to golfers and fans.

On the opening day of the tournament (Thursday January 23rd) rain persisted all day. By late afternoon, accumulated rainfall on the greens forced cancellation of play. Frequent showers were observed all day Friday, but (though putted balls made wakes like a destroyer) play was completed by nightfall. On Saturday, the winds came - with gusts to over 30 knots in the afternoon. In the early hours of Sunday morning, gusting peaked to an estimated 70 to 75 knots causing serious damage to some communications equipment and to trees on the Spyglass course.

Light hail for about 5 to 8 minutes around noon on Sunday caused some confusion. One fan, racing for the shelter of a tree, arrived to find himself in stocking feet and his shoes stuck, a pace apart, in the soggy grass beside the fairway. The intermittent showers did not force cancellation of play, however. Because of Thursday's cancellation, the final round was played on Monday. This turned out to be the best day of the tournament, but the scattered showers changed to rain late in the day as the last finishers putted-out.

Of course, the working press gobbled up all available weather information to tie in with their sports coverage. Television technicians, directors and commentators made frequent reference to the Crosby Weather Board. Satellite photos furnished by the Fleet Numerical Weather Central in Monterey drew considerable interest.

An interesting statistical analysis was also made of the effects of weather on golfing strategy and scores. Dr. David Schrady, a professor at the nearby Naval Postgraduate School, together with a volunteer weather observer, noted player strategy, weather conditions and scores at the (in) famous 16th hole at Cypress Point. Unfortunately, the weather was so overwhelmingly bad that few final conclusions could be reached. The results of this study will appear in the January 1970 issue of "Golf Digest".

Of course Crosby Weather is not always inclement. In fact, weather conditions for some tournaments have outdone even the optimistic assurance of the Monterey Chamber of Commerce. It is the conclusion of local meteorologists that Crosby Weather is best defined as "extremely variable".

Crosby golfers and fans are probably the most amenable customers a meteorologist could ever hope for. Explanations about blocking highs, cyclonic activity, troughing, etc., etc., are of little concern to them. Benign or malevolent, all meteorological conditions during a particular week in January are accepted with good nature and grace as simply part of the event. After all, it's just "Crosby Weather".

WIND-INDUCED WATER LEVEL CHANGES IN LAKES

by

JOHN NOYE

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In addition to seasonal changes in water level, such as a rise, in Winter, due to inflow from rivers and a fall, in Summer, due to evaporation, the water level in a given part of a lake may change periodically at intervals of one day or less. These changes are characterised by a fall in water level in one part of the lake being associated with a rise in level in another part. The principal causes of these short term variations are varying wind set-ups caused by changing wind forces and sustained natural oscillations, called seiches.

Wind Set-Up

In a lake the drag of the wind across the surface causes a current to flow, in the upper layers of the water, in the same direction as the wind and equilibrium is restored by a current in the lower layers flowing in the opposite direction. To overcome the resistance to the currents in the lower layers a tilt of the water surface occurs, by which the level of the lake is lowered at the windward side and raised at the opposite shore. The surface slope is called wind set-up. It is illustrated in Figure 1 for a westerly wind blowing across a lake and producing a rise in the water-level on its east shore. The greater head at the eastern shore produces a pressure differential which over-comes the bottom friction acting on the return current which flows westward.

In a similar fashion diurnal and semidiurnal oscillations in the wind, such as alternating land and sea breezes over lakes near the coast, will induce forced oscillations in the water surface with the same period as the wind oscillations.

The wind set-up is distinct from the phenomenon of ordinary progressive surface waves caused whenever the wind blows over a water surface. Set-up may also occur in the sea; prolonged offshore winds have been known to raise the sea-level many feet. In the book of tide-tables printed each year by the South Australian Department of Marine and Harbours it is stated that "At Port Adelaide N.W. winds cause the highest tides, raising sea level up to 4 ft. above normal, while continuous S.E. winds depress it as much as 1½ ft."

Wind effects must not be confused with seiches, the free oscillation of the whole mass of water in a lake with the associated rhythmic motion of the water surface.

Seiches

Most seiches are caused by abrupt changes in wind force. Consider a lake elongated in the E-W direction. The stress on the lake surface caused by a strong easterly wind that has been blowing for some time elevates the surface level in the west and depresses the surface in the east. If the wind stress diminishes, due to a change in speed or direction of the wind, the potential energy of the water in the west will cause water to flow towards the east. The result will be a "pile-up" in the east giving rise to a current back towards the west. One cycle is completed when again there is maximum elevation of water in the west. The time which elapses during this cycle is called the period of the motion.

This process is illustrated in Figure 2. Initially there is the "pile-up" of water in the west due to the stress of the steady wind. At the moment the wind stress in this direction stops, there is no current. After one-quarter of the period T there is no deviation in the surface from the mean position but the strength of the current is a maximum. The figure shows that after ½T there is no current but elevation

in the east is a maximum. At 3/4T there is maximum current towards the west and no deviation of the surface. After time T the first cycle is completed.

The oscillation just described is a seiche with antinodes (positions of maximum movement of the water surface) at the closed ends of the lake and a node (position of no movement of the water surface) at the centre. This motion will continue until damped by friction or new disturbances.

Seiches can take different forms depending on the number of nodal lines. At these lines the height of the water remains unaltered during the whole period of the oscillation, while the maximum amplitudes of the surface oscillations occur at the anti-nodal lines.

The uninodal seiche is characterised by one nodal line across the middle of the lake, and two antinodal lines across the ends. The motion of the surface of the lake can be regarded as an oscillation having the node as an axis, the result being a rise of the water level at one end of the lake with a simultaneous lowering at the other end, and vice versa. The binodal seiche has two nodal and three anti-nodal lines, and the water level rises simultaneously at both ends of the lake, whilst there is a depression in the middle, and vice versa. The trinodal seiche has three nodal and four antinodal lines, and so on. In a lake the period (time of oscillation) of a binodal seiche is approximately one-half that of the uni-nodal seiche, the period of a trinodal seiche is nearly one-third that of the uninodal seiche, etc. Figure 3 illustrates these three types of seiches.

In a lake seiches of any nodality are possible, and every observed seiche is either one of those already mentioned, when the seiche is called pure, or a combination of seiches of different nodality. The most common seiche appears to be the one in which the uninodal and binodal seiches are superimposed upon one another.

The seiche formed in any lake has a period which depends on the topography of the lake and the number of nodes in the seiche. This is evident in Merian's formula which gives the period of longitudinal seiches in a rectangular lake of constant depth. The uninodal seiche in such a lake of depth D and length L has a period T given by

$$T = \frac{2L}{\sqrt{gD}} \quad , \qquad (1)$$

where g is the acceleration due to gravity. For seiches with more than one node the period is

$$T_n = \frac{2L}{n\sqrt{gD}} \quad , \qquad (2)$$

where n is the number of nodes in the oscillation. For an elongated lake of reasonably constant depth these formulae give good approximations to the seiching periods of the lake. If L miles is the average length of the lake and D feet the average depth, the period of the uninodal seiche is approximately T minutes where

$$T = \frac{44L}{\sqrt{2D}} \quad , \qquad (3)$$

For instance, during 1951 Lake Eyre in South Australia had an average length of 90 miles and an average depth of 8 feet, so the corresponding uninodal seiche at that time had a period of nearly 17 hours.

Seiches Versus Wind Effects

Having been generated by some external cause, seiches continue without the action of any forces other than those of gravitation and friction in the water, the latter having a suppressing effect upon the movement. They are most easily observed during the calm weather, but often occur simultaneously with a wind set-up.

The very small friction losses of oscillatory motion in deep water means that seiches are generally more evident in deep lakes. On the other hand, wind set-up becomes more pronounced in shallow lakes where the cross-section of the bottom current, is small, and the flow consequently encounters great resistance which can only be overcome by a comparatively large slope of the water surface.

Since most Australian lakes and reservoirs of any size are very shallow, it is the forcing effect of the wind which is of greatest importance in producing short term water level changes. Water level changes previously attributed to free oscillations or seiches in two large shallow lakes, Lake George near Canberra and Lake Eyre, are undoubtedly forced oscillations due to wind effects. In Reference (1), Bonython refers to seiches in Lake Eyre during the first seven days of December in 1951. However, a careful examination of the wind speed and direction during this time shows that the water levels recorded at the south east end closely follow the south-easterly component of the wind stress, which is directed along the central axis of the lake. For instance, a north-west squall during the night of the lst day of December produced a rapid rise of more than two feet, and a strong south wind during the morning of the 7th day produced fall of twenty inches which caused the waters' edge to retreat more than half a mile.

Field Experiments

In December of both 1966 and 1967, the author conducted very successful experiments in the Coorong Area and at Lake George (see Figure 4) with the help of members of The Horace Lamb Oceanographical Centre and students from South Australian Secondary Schools.

The Coorong is an unusual body of sea-water, some two miles wide and sixty miles long, separated from Encounter Bay by Younghusband Peninsula, a row of sandhills between one-half and one mile wide. The South Coorong extends from a narrow channel called Hell's Gates, near Magrath Flat, to Bul-Bul Basin just south of Salt Creek, a distance of about twenty-five miles (see Figure 5). It has an average depth of nearly 4 feet in Summer.

The Coorong Experiment held in December 1966, indicated that the dominant cause of the daily variation in water level of the South Coorong was the wind-effect (see References (2) and (3)). The wind component along the Coorong oscillated daily about a mean value of 10 knots, a maximum speed of about 20 knots being recorded in the late afternoon, there being a flat calm in the early hours of the morning. In phase with the maximum intensity of the south-east wind component, at about four o'clock in the afternoon, the water level in Bul-Bul Basin reached its lowest level and that in Stony Well Basin reached its highest point. With the calm about four o'clock in the morning the water level in Bul-Bul Basin reached its highest value and that in Stony Well Basin was at its lowest.

This experiment was designed to detect evidence of seiching, and field stations recording water levels at 5 minute intervals were placed on both sides of the Coorong in Stony Well Basin and Bul-Bul Basin, with an additional station half way between at Fat Cattle Point. The wind velocity and atmospheric pressure were measured every 20 minutes at Bul-Bul Basin and Hell's Gates so that any atmospheric excitation of seiches could be identified. Strong evidence was found for cross-seiching in Stony Well Basin but the wind set up was dominant in all records taken.

The 1967 experiment was designed to establish the connection between the wind velocity and water levels, with all readings being taken at 5 minute intervals. Two field stations were established, one on an unnamed island at the north end of Stony Well Basin and which was christened Noye's Island by the students manning the station and one on Salt Creek Point at the south end of Salt Creek Basin. Measurements of water level, wind speed and direction, atmospheric pressure, and surface drift in the water, were recorded at each station for 98 hours. The results clearly showed a strong linear connection between the wind stress component along the centreline of the South Coorong and water level changes at the ends. Figure 6 shows the similarity between the graphs of wind stress component and the difference in water level between Noye's Island and Salt Creek Point.

During the running of both experiments many traverses of the South Coorong were made using several motor-boats and numerous soundings were taken. From these readings the surprisingly small average depth of only four feet was established for Summer conditions. Samples of water were also collected and taken to Flinders University for analysis on a salinometer. The results showed the effect of excessive evaporation in the Coorong; the water was three times as saline as samples of sea-water collected from the Southern Ocean.

At the same time a similar experiment was conducted at Lake George, near Beachport, in the South East. Two field stations on the centre basin and three field stations on the north basin recorded water levels, and a meteorological station on a sand-spit between the two basins recorded atmospheric pressure and wind velocity, all at five minute intervals. Again the results indicated that the main cause of water level changes was the changing magnitude and direction of the wind stress.

CONCLUSION

The wind induced changes in the water levels of shallow bodies of water can be large. A reversal of wind direction in the South Coorong in December 1967, caused a drop of more than one foot in level at the north end and a corresponding rise at the south end.

Such sudden changes in the water level of Lake Albert have sometimes prevented surrounding pastoralists from pumping the fresh water needed to irrigate their large areas of lucerne. This is also an acute problem in the larger Lake Alexandrina where wind effects have been known to temporarily change the water level by as much as three feet, leaving the inlet pipes of the pumps well out of the water.

The wind effects may possibly cause increasing salinity in Lake Albert. The dominant southerly winds cause the fresher surface water to flow through the Narrung Channel into Lake Alexandrina leaving the more saline lower layers to accumulate and increase in concentration through evaporation.

With strong northerlies the level at the south end of Lake Alexandrina rises, and if these winds persist, water may be lost into the Coorong over the barrages. This same effect will undoubtedly need to be taken into account when the Chowilla Dam is constructed; a persistent strong east wind could cause overtopping of the embankment with the possibility of weakening through erosion. Further research is in progress which should produce suitable formulae for the calculation of wind set-up in very shallow lakes, lagoons and dams, all of which are common in Australia.

Acknowledgments

The writer thanks The Horace Lamb Centre for Oceanographical Research for the use of data he collected with the assistance of the many secondary school pupils at the Coorong and Lake George, during the time he was a Research Fellow at Flinders University. He also thanks the Commonwealth Bureau of Meteorology who supplied instruments for measuring wind speed and barometric pressure for both the 1966 and 1967 experiments, and the S.A. Department of Marine and Harbours for permission to use the quotation from their book of Tide Tables.

References

(1) A. Grenfell Price, F.C. Martin, B. Mason and C. Warren Bonython, "Lake Eyre, South Australia - The Great Flooding of 1949-50". Report of the Lake Eyre Committee, S.A. Branch of the Royal Geographical Society of Australasia, 1955 (Griffin Press, Adelaide) 75pp.

(2) John Noye, "A Limnological Study of the Coorong" Research Paper No. 11, Horace Lamb Centre for Oceanographical Research, July 1967.

(3) B.J. Noye, "Wind Tides and Seiches in a Shallow Lagoon" Proceedings Section 8, 41st Congress, Australian and New Zealand Association for the Advancement of Science, Adelaide, August 1969.

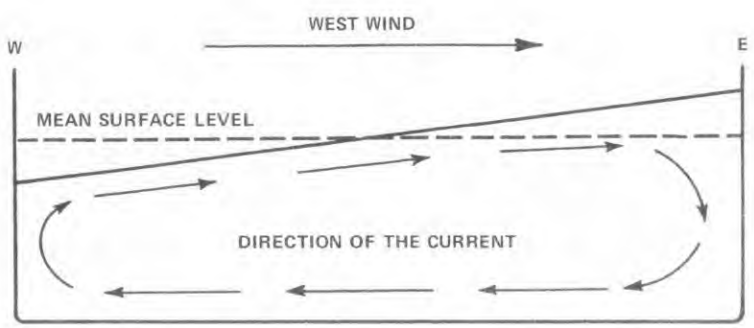

Figure 1: Wind set up of a lake due to a steady west wind.

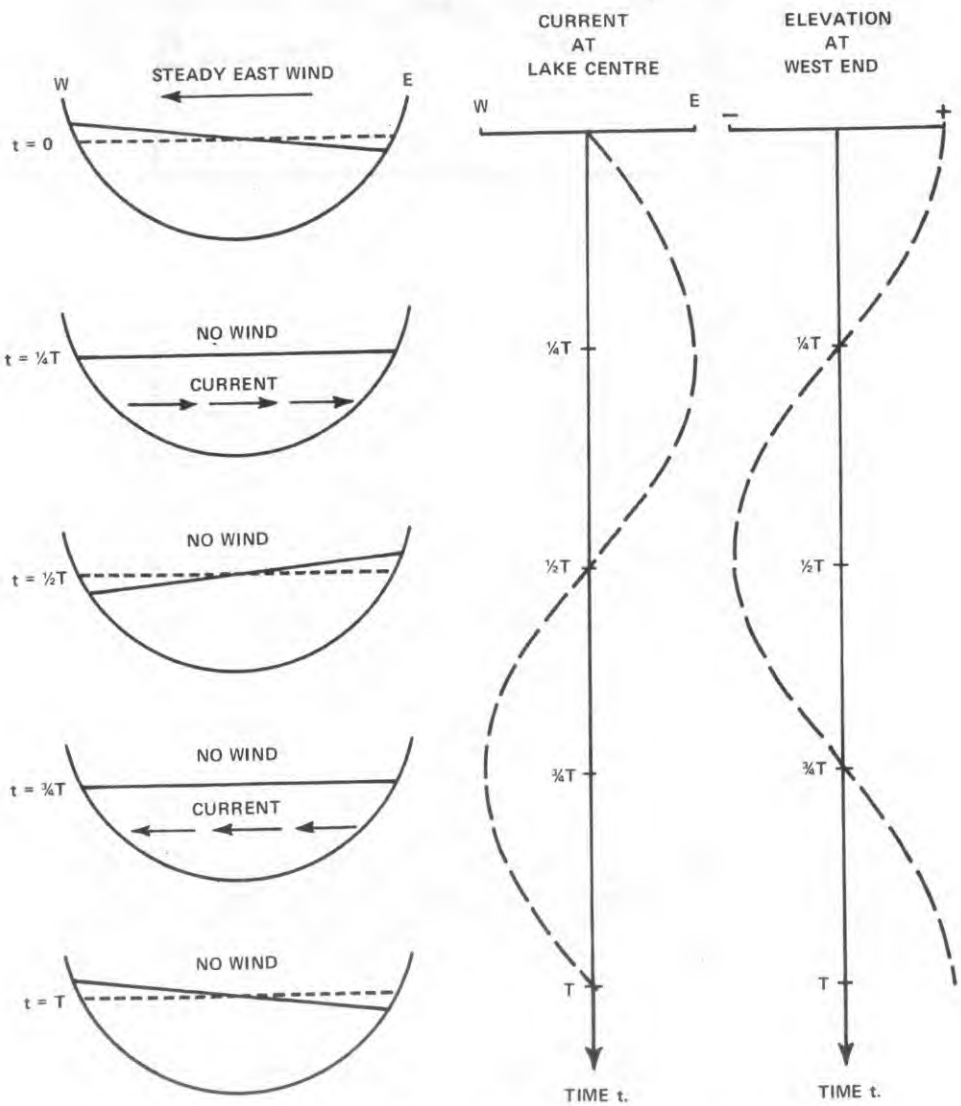

Figure 2: Four phases of water level elevations and currents during a uni-nodal seiche.

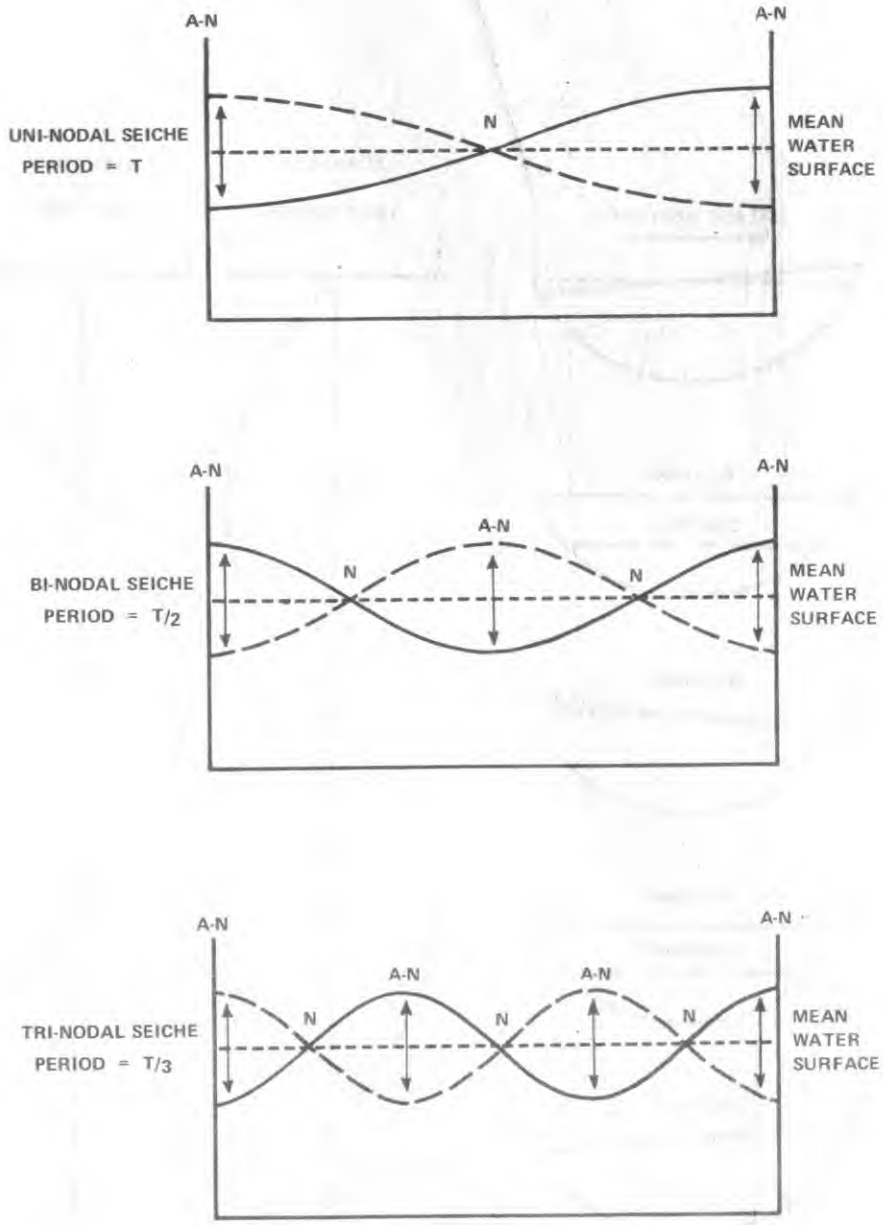

Figure 3: Cross-section of uni-nodal, bi-nodal and tri-nodal seiches in a rectangular lake of constant depth. Positions of nodes are indicated by N, and of anti -nodes by A-N.

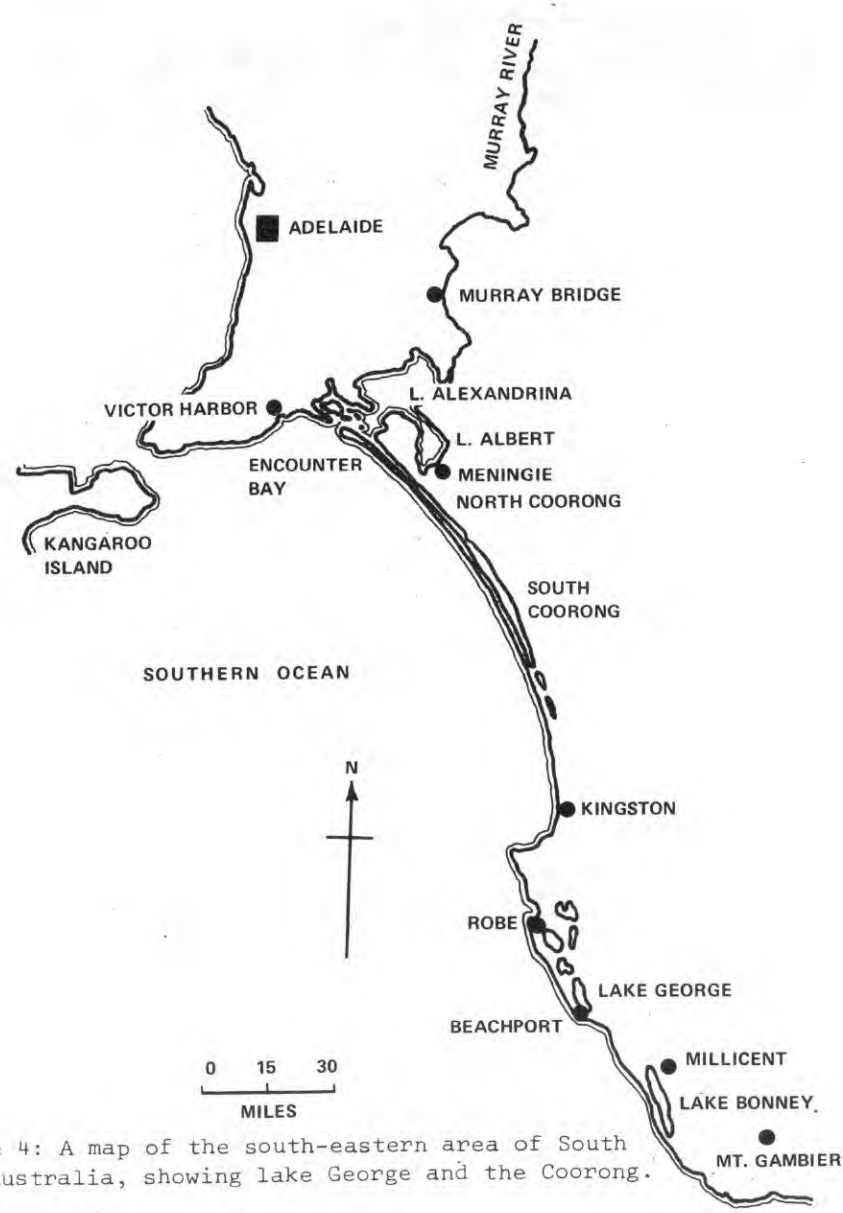

Figure 4: A map of the south-eastern area of South Australia, showing lake George and the Coorong.

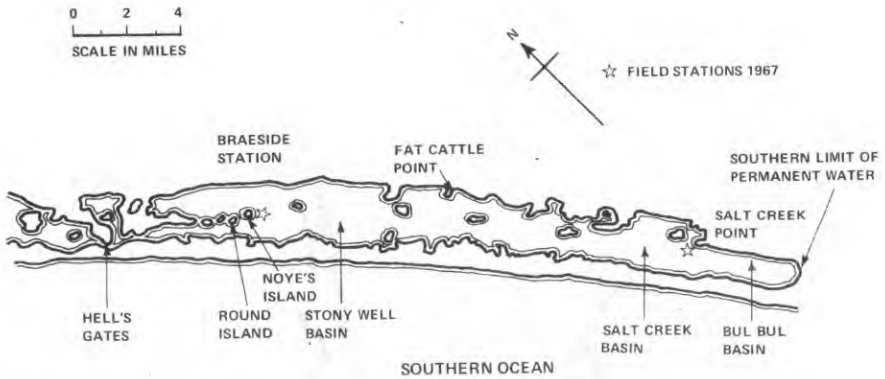

Figure 5: Map showing the Coorong south of Hell's Gates

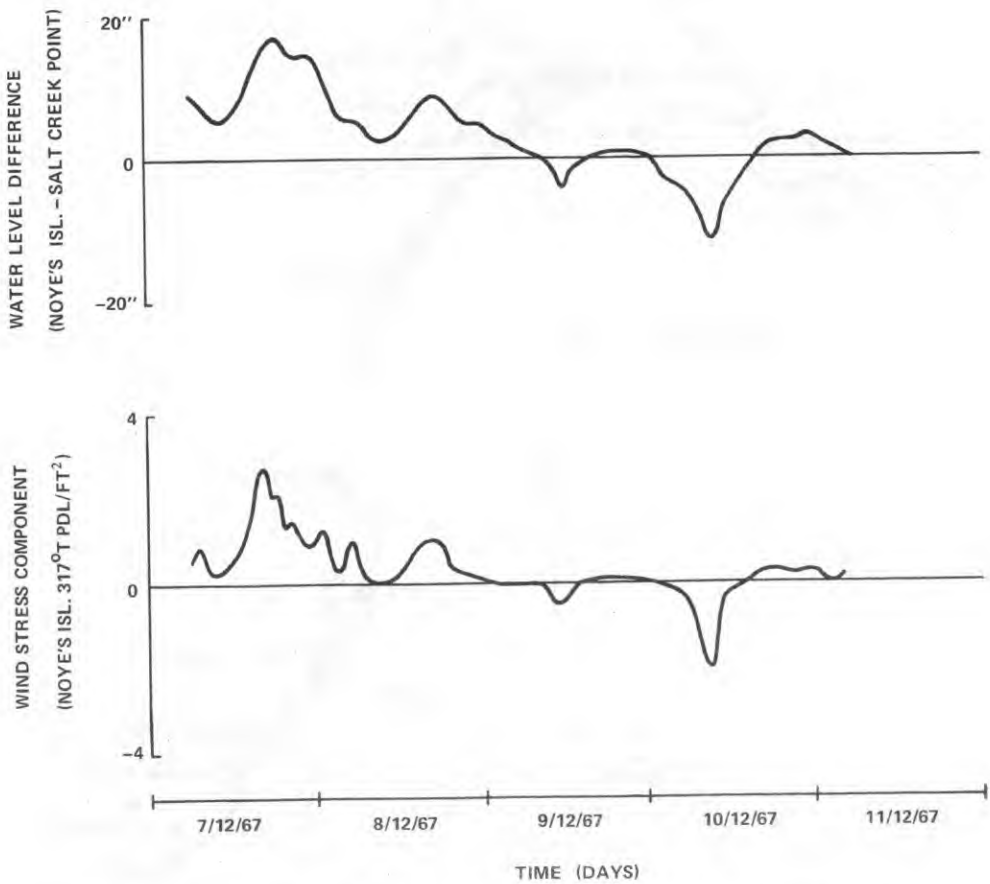

Figure 6: Graph of the difference in water level between the two ends of the South Coorong compared with the graph of the component of the wind stress along the Coorong.

VISIT OF INSPECTION - BUREAU OF METEOROLOGY

The 10th Meeting of the Association on Sunday 6th December, 1970, took the form of a visit of inspection to both the Regional Office of the Bureau of Meteorology and to the Radar-Radiosonde Station at the Airport.

In all, about 150 Members attended the Radar Station, where they were in the capable hands of Murray Weaver and two helpers. Three theodolites, including one for the biggies and one for littlies, were set up to enable visual tracking of wind-finding balloons - aided and abetted by excellent weather with only about 1/8 scattered cloud. In fact, balloons could be clearly seen to 15,000 feet with the naked eye.

An ideal synoptic situation prevailed for the purpose, indicating how vastly-differing wind regimes at different levels can co-exist. A Southwesterly sea breeze dominated the first 2,000 feet, with over this a quite fresh Easterly. At 10,000 feet a Westerly wind was blowing. It was quite evidently a surprise to many that 3 different airstreams could persist simultaneously within the first 10,000 feet of the atmosphere. Radar and Radiosonde operations were also demonstrated.

At the Regional Office the Members were treated to guided tours of the instrument enclosure, the communications room, forecasting office and even a mini-tour of Mr. Hogan's art gallery of various spectacular weather phenomena which includes cold front clouds, dust storms and fossilised hail stone imprints 150 million years old.

Surprisingly, even the dusty tower attracted many starters, who were rewarded for their steep climb by a unique birds-eye view of much of Adelaide and a few near heart attacks.

In all, enthusiasm for the whole tour was evident, many Members taking notes and others keeping up a steady flow of interested questions in all that they saw.

BUREAU OF METEOROLOGY

CLIMATOLOGICAL STATISTICS - BUREAU OF METEOROLOGY, ADELAIDE
PERIOD OF RECORD 114 YEARS 1857 - 1970 INCLUSIVE

*Average of highest each year
**Average of lowest each year

MONTH	AV. MAX. °F	AVERAGE OF HIGHEST EACH MONTH °F	AV. MIN. °F	AVERAGE OF LOWEST EACH MONTH °F	AVERAGE $\frac{MAX+MIN}{2}$ °F	HOTTEST DAY (Highest max. on record)	COLDEST DAY (Lowest Max. on record)	HOTTEST NIGHT (Highest Min. on record)	COLDEST NIGHT (Lowest Min. on record)	AVERAGE NUMBER OF DAYS 90° or over	100° or over	40° or under	AVERAGE TEMPERATURES 9 a.m.	3 p.m.
JAN.	85.4	106.7	61.5	51.2	73.5	117.7°F 12/1939	61.0°F 17/1868	95.1°F 27/1858	45.1°F 21/1884	10.3	4.0	0.0	75.1	81.4
FEB.	84.9	104.2	61.8	51.5	73.3	113.6 12/1899	60.5 27/1939	90.9 12/1899	45.5 23/1918	9.0	2.7	0.0	74.4	81.1
MARCH	80.4	98.9	59.0	49.4	69.7	110.5 9/1934	58.5 16/1879	84.1 4/1942	43.9 21/1933	5.5	1.0	0.0	70.5	76.9
APRIL	72.9	88.5	54.6	45.8	63.7	98.6 5/1938	52.6 25/1938	79.6 2/1887	39.6 15/1859	0.7	0.0	0.0	64.1	69.8
MAY	65.6	77.4	50.4	41.9	58.0	89.5 4/1921	52.0 12/1884	69.8 3/1921	36.9 26/1895 24/1904	0.0	0.0	0.4	57.4	62.9
JUNE	60.5	67.9	46.9	38.7	53.7	78.1 4/1957	48.0 28/1904	63.4 3/1957	32.5 27/1876 24/1944	0.0	0.0	2.4	52.4	58.2
JULY	58.9	66.5	44.9	37.2	51.9	74.0 11/1906	47.2 23/1879	58.9 4/1877	32.0 24/1908	0.0	0.0	4.3	50.6	56.7
AUG.	61.6	72.3	46.0	38.1	53.8	85.0 31/1911	48.7 11/1960	65.1 24/1871	32.3 17/1859	0.0	0.0	2.9	53.4	59.0
SEPT.	66.1	81.1	48.1	39.7	57.1	95.1 30/1961	51.0 11/1880	73.3 29/1944	32.7 4/1858	0.1	0.0	1.2	58.1	62.9
OCT.	71.8	90.9	51.5	41.7	61.7	102.9 21/1922	52.1 1/1968	77.0 20/1861	36.1 20/1858	1.3	0.1	0.3	63.6	68.1
NOV.	77.5	98.5	55.2	45.2	66.3	113.5 21/1865	56.2 6/1953	86.3 30/1922	40.8 2/1909	4.6	0.7	0.0	69.0	73.5
DEC.	82.1	103.8	58.8	48.7	70.5	114.6 29/1931	59.8 3/1955	88.2 29/1897	43.0 16/1861 4/1906	7.8	2.3	0.0	72.8	77.9
YEAR	72.3	108.9*	53.2	36.2**	62.7	117.7 12/1/1939	47.2 23/7/1879	95.1 27/1/1858	32.0 24/7/1908	39.3	10.8	11.5	63.5	69.0

BUREAU OF METEOROLOGY

RAINFALL STATISTICS - BUREAU OF METEOROLOGY, ADELAIDE
(FOR 132 YEARS OF RECORD 1839 - 1970)

MONTH	MONTHLY RAINFALL POINTS				RAINFALL 1ST JANUARY TO END OF MONTH - POINTS				DAILY RAINFALL POINTS	
	AV. NO. DAYS RAIN	AVERAGE TOTAL	GREATEST TOTAL	LEAST TOTAL	AV. NO. DAYS OF RAIN	AVERAGE TOTAL	GREATEST TOTAL	LEAST TOTAL	GREATEST IN 24 HOURS TO 9 A.M.	GREATEST IN 48 HOURS TO 9 A.M.
JANUARY	4	76	331 1941	Nil Several	4	76	331 1941	Nil Several	230 2/1889	308 25/1941
FEBRUARY	4	79	609 1925	Nil Several	8	155	649 1925	Nil 1848	557 7/1925	557 7/1925
MARCH	5	94	459 1878	Nil 1859 1864 1870	13	249	710 1877	46 1965	350 5/1878	360 6/1878
APRIL	10	171	581 1938	Nil 1945	23	420	961 1889	75 1888	315 5/1860	328 17/1938
MAY	13	272	775 1875	10 1934	36	692	1373 1889	223 1891	275 1/1853	377 2/1853
JUNE	15	287	858 1916	23 1958	51	979	1851 1889	290 1959	211 1/1920	301 2/1920
JULY	16	260	544 1890	39 1899	67	1239	1986 in 1847 & 1956	438 1959	175 10/1865	237 10/1865
AUGUST	16	244	620 1852	33 1944	83	1483	2332 1889	623 1959	223 19/1851	228 19 & 20/1851
SEPTEMBER	13	200	583 1923	27 1951	96	1683	2595 1851	750 1959	159 20/1923	225 21/1923
OCTOBER	11	172	524 1949	4 1969	107	1855	2845 1889	839 1959	224 16/1908	310 16/1908
NOVEMBER	8	121	445 1839	5 1967	115	1976	3070 1851	932 1959	296 12/1960	335 8/1934
DECEMBER	6	104	398 1861	Nil 1904	121	2080	3095 1851	1011 1967	242 23/1913	322 28/1929
YEAR	121	2080	858 June 1916	Nil Several	121	2080	3095 1851	1011 1967	557 7.2.1925	557 7.2.1925

BUREAU OF METEOROLOGY

CLIMATOLOGICAL STATISTICS - BUREAU OF METEOROLOGY, ADELAIDE

MONTH	AVERAGE RELATIVE HUMIDITY 103 Years 1868-1970		AVERAGE PRESSURE 114 years 1857-1970 (9 a.m. + 3 p.m.) / 2	AVERAGE EVAPORATION from Australian Tank 95 years 1870-1966 (1961 & 1962 incomplete)	AVERAGE SUNSHINE 89 years 1882-1970		WIND 54 Years 1917-1970	PHENOMENA Period 98 years 1872-1970 Average number of days					
	9 a.m.	3 p.m.	Mean Sea Level (Mb)	INCHES*	Daily Hours	Monthly Hours	Max. Gust in m.p.h.	HAIL	DEW	LIGHT-NING	THUNDER	FOG 71 YEARS	FROST TERRESTRIAL <30.4 DEGREES F 108 Years
JAN	40%	32%	1013.3	9.29	10.0	308.5	72NNW 7/1942	0.1	3.4	2.1	1.5	0.0	0.0
FEB	43	33	1014.3	7.52	9.3	261.5	66ESE 7/1955	0.1	5.4	1.7	1.1	0.0	0.0
MAR	47	37	1017.2	6.26	7.8	242.8	78W 5/1956	0.1	9.5	1.7	0.8	0.0	0.0
APRIL	56	46	1019.8	3.78	5.9	179.6	81SW 11/1948	0.3	12.4	1.4	1.0	0.0	0.1
MAY	67	55	1020.1	2.30	4.8	146.7	70WSW 12/1960	0.5	14.6	1.5	1.0	0.4	0.5
JUNE	75	63	1019.7	1.47	4.2	124.0	67WNW 19/1943	0.7	14.3	1.5	0.9	1.1	2.1
JULY	76	63	1020.0	1.47	4.3	132.7	92W 13/1964	0.8	15.3	1.5	0.8	1.3	3.1
AUGUST	70	58	1019.1	2.09	5.2	162.2	75WSW 1/1962	0.8	14.9	1.7	1.1	0.6	1.9
SEPT.	60	51	1017.6	3.18	6.1	184.1	69WNW 15/1942	0.9	14.0	1.8	1.4	0.2	0.8
OCT.	51	43	1016.0	5.03	7.2	223.3	75WSW 1/1955	0.6	11.2	2.7	1.9	0.0	0.2
NOV.	44	36	1015.1	6.78	8.5	255.2	81NW 19/1962	0.3	6.0	3.0	2.0	0.0	0.0
DEC.	40	34	1013.3	8.62	9.4	292.1	75SW 1/1935	0.1	4.1	2.2	1.5	0.0	0.0
YEAR	56	46	1017.1	57.79	6.9	2512.7	92W 13/7/64	5.3	125.1	22.8	15.0	3.6	8.7

Highest Mean Sea Level Barometer Reading 1041.0 millibars 16th August 1932.
Lowest Mean Sea Level Barometer Reading 985.0 millibars 12th July 1964.

* Class 'A' Pan methods instituted January 1967 - records not strictly comparable with those from Australian Tank.